

# X-ray experiments for Space applications in intermediate energy range

Vipin K. Yadav<sup>\*†</sup>, Sandip K. Chakrabarti<sup>‡\*</sup>, Anuj Nandi<sup>\*†</sup>, Sourav Palit<sup>\*</sup>.

<sup>\*</sup> Indian Centre for Space Physics, 43 Chalandika, Garia Station Road, Kolkata - 700084, India.

vipin@csp.res.in, anuj@csp.res.in, sourav@csp.res.in

<sup>†</sup> Indian Space Research Organization HQ, New BEL Road, Bangalore - 560231, India.

<sup>‡</sup> S. N. Bose National Centre for Basic Sciences, Block-JD, Sector-III, Salt Lake, Kolkata - 700098, India.

Email: chakraba@bose.res.in

**Abstract**—X-ray experiments in the intermediate energy range (1-50 keV) are carried out at the Indian Centre for Space Physics (ICSP), Kolkata for space application. The purpose is to carry out developmental studies of space instruments to observe energetic phenomena from compact objects (black hole and compact stars) and active stars and their testing and evaluation.

The testing/evaluation setup primarily consists of an X-ray generator, various X-ray imaging masks, an X-ray imager and an X-ray spectrometer. The X-ray generator (Mo target) operates in 1-50 kV anode voltage, and 1-30 mA beam current. A forty-five feet long shielded collimator is used to collimate the beam which leads to the detector chamber. The angular diameter of the X-ray beam at this distance becomes  $\approx 30$  arc-sec.

Two types of imaging masks are being studied with: One is the conventional Coded Aperture Masks (CAM) and other is the Fresnel half-period zone-plates (ZPs) made of Tungsten. The latter has finer zones of 40-50 microns rendering achromatic angular resolutions of a few tens of arc-sec when two ZPs are kept at a distance of only 30 cm. By increasing space between the ZPs one can achieve as high resolution as necessary as long as the pointing accuracy is good enough. The Moire fringe pattern produced by the composite shadows of two ZPs is inverse Fourier transformed to obtain the X-ray source distribution. CAMs are advantageous as they are single element devices, but the resolution obtained is limited by their smallest pixel size.

A complementary metal-oxide semi-conductor (CMOS) detector connected to a PC is used as the X-ray imager. This produces digitized image and can be further analyzed. For spectroscopy a Si-PIN photo-diode based detector is used. Several standard radioactive sources are used as calibrators.

Our setup has been extensively used in testing and evaluation of the Roentgen Telescope (RT)-2 payloads which have been launched recently (30th Jan. 2009). More experiments for improving imaging techniques are being designed and tested.

## I. INTRODUCTION

Study of compact objects are usually done by detecting high energy photons emitted by accreting matter. Similarly stars in active period also emit high energy radiation which may be detected and their properties can be studied. Large number of telescopes have been launched in the past to study both the compact objects, the sun and other stars.

An energy range of importance belongs to the soft and intermediate region (1-50 keV) where moderately active objects emit substantial number of photons. Spectrophotometry and imaging in this range is our priority. Though our laboratory is quite new, we have made our mark by participating in building three payloads named RT-2 for the Russian satellite

KORONAS-FOTON. In this paper we present some of our studies.

## II. THE X-RAY SOURCE

The X-ray beam is emitted from the generator having anode voltage in the operating range of 0-50 kV and the beam current between 0-30 mA. The X-ray target crystal is Molybdenum, which has good  $K_\alpha$  and  $K_\beta$  line features. The X-ray beam when used at 45 feet away is not quite a parallel beam but it can be treated as a quasi-parallel (with little divergence) x-ray beam. The X-ray beam diameter ( $l$ ) is 2 mm and the X-ray collimator length ( $L$ ) is 45 feet (13716 mm). Hence, the beam divergence at a distance of 45 feet is  $\sim 30$  arcsec. The X-ray beam from the source to a distance of 45 feet is guided through a 7.5 cm diameter Aluminium pipe-line. This pipe-line is covered throughout its length by a 2 mm thick lead sheet for shielding.

## III. THE IMAGING DEVICES - ZONE PLATES

ICSP has been toying with both the conventional Coded Aperture Masks (CAMs) as well as Fresnel Zone Plates (FZPs) [1], [2]. CAMs are widely used, but higher resolutions can be achieved by FZPs as well. Two aligned zone plates will cast Moire fringes when the source is off-axis (Figure 1). The fringe pattern can be appropriately inverse Fourier transformed to get back the source pattern.

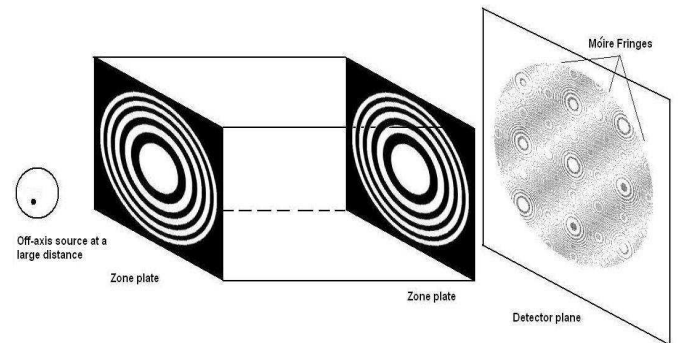


Fig. 1: The zone-plate working principle.

At ICSP, we have designed zone plates and got them fabricated using copper and tungsten. The copper zone plates can be used only for soft X-rays but the latter can be used for hard X-rays also. The advantage with copper zone plates is that they are less expensive to build and can be made in large sizes also. In figure 2, the various types of these zone plates are depicted.

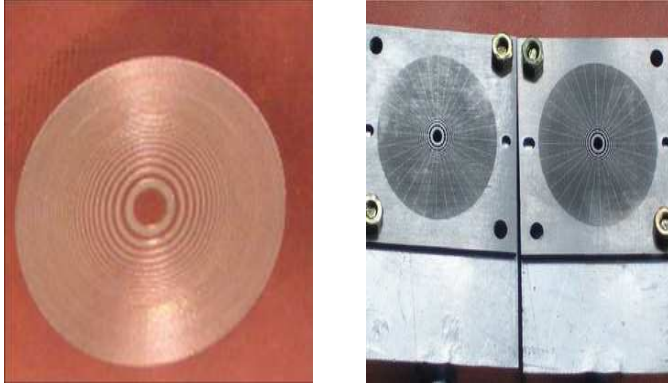


Fig. 2: The Fresnel zone-plates made of copper (left) and tungsten (right).

#### IV. THE DETECTION SYSTEM

The detector systems used to record the experimental results are X-ray films, Amptek made Si-PIN detector with 25  $\mu\text{m}$  thick Be window for low energy X-rays (Energy resolution at 5.9 keV  $Fe_{55}$ , 145 eV FWHM), Rad-ikon made RemoteRad-Eye CMOS imager (1024 pixels  $\times$  1024 pixels) and Orbotech made CZT (Cadmium Zinc Telluride) detectors.

In Figure 3 we have shown the placement of the Si-PIN photodiode detector at the end of 45 feet long X-ray beam-line during the experiments conducted.



Fig. 3: The Si-PIN detector installed at the end of 45 feet shielded x-ray beam-line.

As can be seen from the figure, the Si-PIN detector is mounted on a custom built optical bench and the detector can be linearly shifted by 1 mm if required.

In Figure 4 we have shown the placement of the CMOS detector at the end of 45 feet long X-ray beam-line during the testing campaign [3].



Fig. 4: The CMOS detector installed at the end of 45 feet shielded X-ray beam-line.

Some of the experimental results obtained using these detecting devices are presented the following sections.

#### V. EXPERIMENTAL RESULTS

In the left side of the Figure 5, the X-ray image of the copper Zone plate is shown as obtained at a distance of 45 feet by the CMOS detector. As expected the image is blur due to poor blocking of X-rays by the copper. To increase the X-ray absorption by the copper zone plates, gold coating is done on to them. The gold plated zone plate clearly is sharper and is blocking hard X-rays as well. This is shown in the right hand side figure 5.

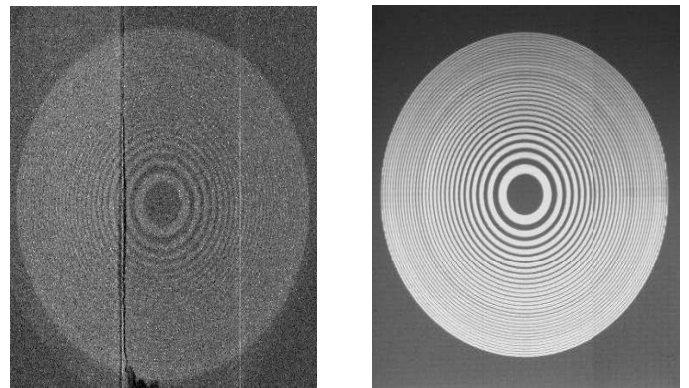


Fig. 5: The CMOS detector images of the copper (70  $\mu\text{m}$  thick) zone plate (left). The CMOS detector images of the copper zone plate coated with 100  $\mu\text{m}$  gold (right).

Experiments are performed with all possible combinations of tungsten zone plates available which include positive (central zone transparent) as well as negative (central zone opaque). The left side photo in figure 6 shows one such positive zone plate. In the same figure on the right side the zoomed in region

of a negative zone plate. The output in both these photos is taken on our CMOS detector.

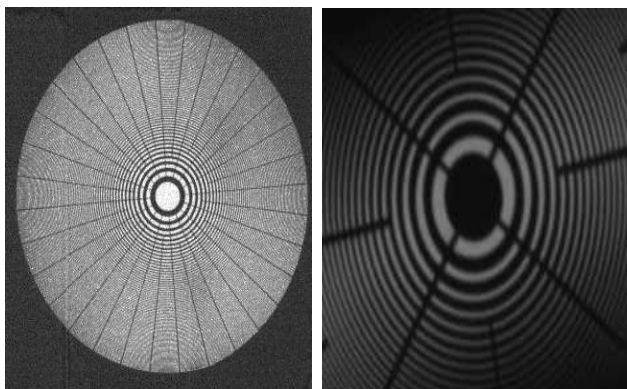


Fig. 6: An image of positive zone plate (left) and a close-up of a negative zone plate (right). The images are taken by the CMOS detector.

Figure 7 shows the Moire fringes obtained on photographic plates by two zone plated separated by 10 cm and the X-ray source is off-axis.

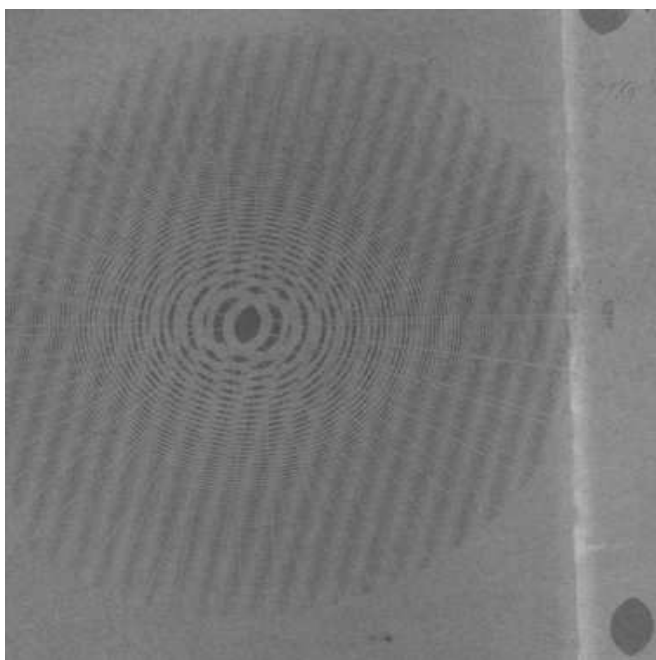


Fig. 7: Moire fringes obtained from two tungsten zone plates on a photographic plate.

It is to be noted here that the photographic plates provides very good resolution.

The moire fringes are also obtained by using two zone plates made from copper and the CMOS detector. However, in this experiment, the zone plate pair is kept in contact with each other. The CMOS image output is faint and is shown in figure 8. The latter fringes are very faint. Therefore, it is decided that in future, the gold plated copper zone plates (Figure 5) are to be used to obtain sharper fringes.

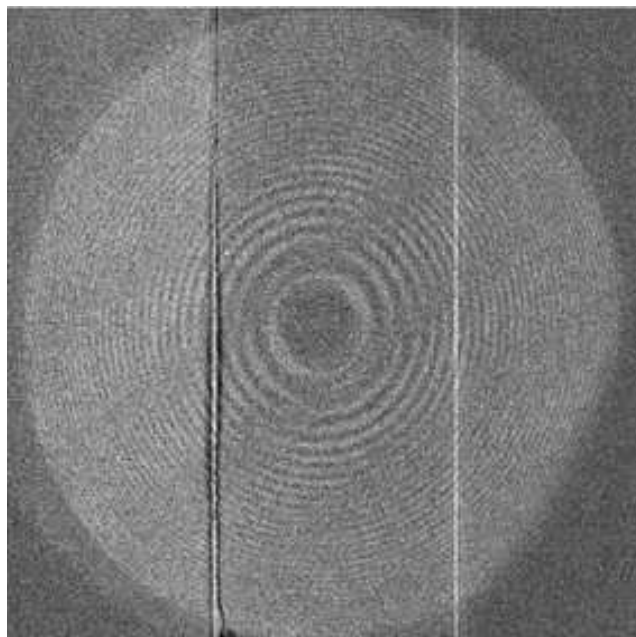


Fig. 8: Moire fringes obtained with two copper zone plates placed back to back.

In Figure 9, we show the Moire fringes on CZT detectors (having a pixel size of 0.25 cm) on the left and CMOS detector (having a pixel size of 50  $\mu m$ ) on the right. We use special IDL programme to obtain source details from these fringes [4].

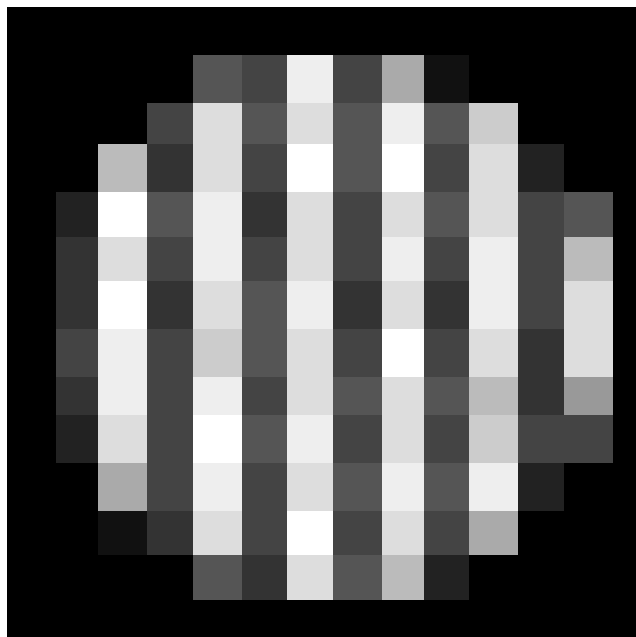


Fig. 9: Moire Fringes of the X-ray source obtained on the CZT detector.

In figure 10, the same source image taken with CMOS detector is shown.

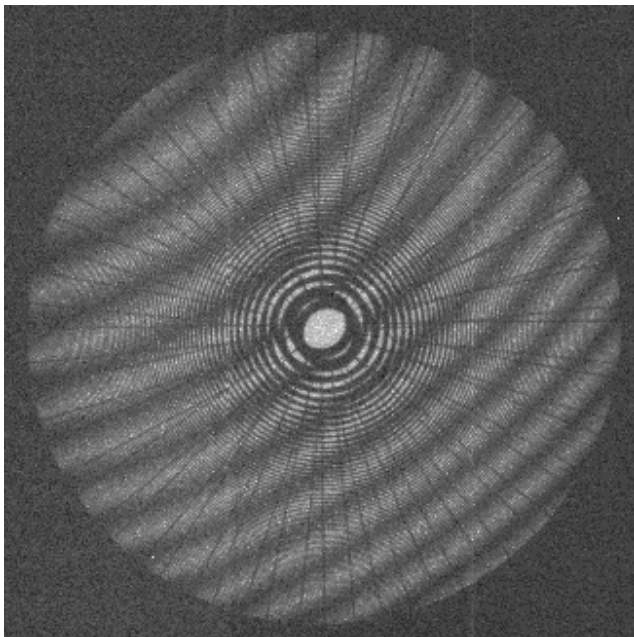


Fig. 10: Moire Fringes for the X-ray source obtained on the CMOS detector.

#### VI. MAJOR TEST AND EVALUATION AT ICSP: RT-2 PAYLOADS

In Figure 11, we show our precision optical bench set up which is used to align components which require alignments accurate to arcseconds using steady laser beams.

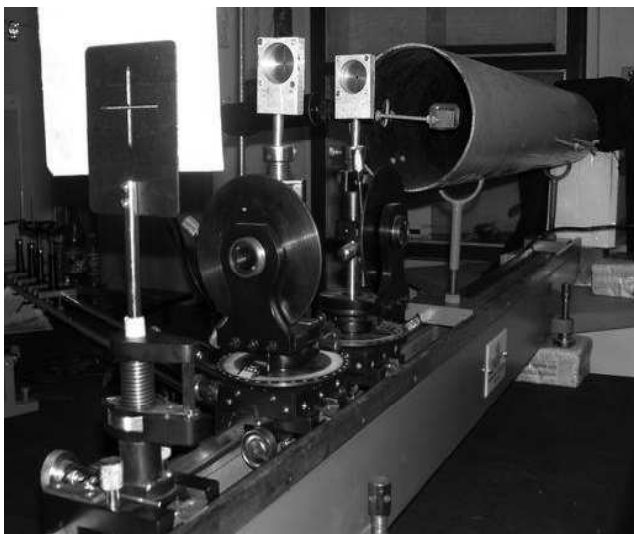


Fig. 11: The Tungsten zone plate pair alignment set-up

This setup has been used to test the collimators with zone plates for the RT-2/CZT payload which has been sent aboard Russian satellite KORONAS-FOTON. A typical testing configuration of the collimator is shown in figure 12. Two different sets of zone plates mounted on the collimator can be seen in this figure.

We have already tested and evaluated another payload namely RT-2/S (a phoswich detector) which is going to work in the



Fig. 12: The RT-2 collimator installed on the x-ray system test bench during testing.

x-ray energy range of 15 - 150 keV. The instruments (RT-2/S and RT-2/CZT) onboard KORONAS-FOTON satellite are launched on January 30, 2009.

#### VII. OTHER ACTIVITIES

Other activities of the ICSP X-ray laboratory includes developmental work on Si-PIN photo-diode based X-ray detector, drift detectors, X-ray counters etc. These are being tested in balloons by ICSP scientists.

#### VIII. CONCLUDING REMARKS

ICSP X-ray Laboratory is equipped with instruments to develop and test and evaluate equipments for space application. We concentrate only on the soft and intermediate X-ray range i.e., 1 - 50 keV. We have participated in RT-2 payloads for the Russian KORONAS-FOTON satellite. We are in a position to propose future missions for continuous spectrophotometry of black holes.

#### ACKNOWLEDGMENT

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